2 MINERνA Physics Goals and Detector Design Drivers

The MINERνA neutrino scattering experiment in the NuMI beam offers a unique opportunity to explore a broad spectrum of physics topics. Some have never been studied systematically, while others are plagued by sparse data with large statistical and systematic errors. The complete MINERνA physics program will include high-statistics studies of all the topics listed below. These studies are important for both the elementary particle and nuclear physics communities, providing information complementary to JLab studies with charged leptons in the same kinematic range.

1. Precision measurement of the quasi-elastic neutrino–nucleus cross-section, including its E_ν and q^2 dependence, and study of the nucleon axial form factors. Over **800 K** events are expected in the fiducial volume during a four-year MINERνA run.
2. Determination of cross-sections in the resonance-dominated region for both neutral-current (NC) and charged-current (CC) interactions, including study of isospin amplitudes, measurement of pion angular distributions, isolation of dominant form factors, and measurement of the effective axial mass. A total of **1.6M** one-pion events make up the low-W resonance sample.
3. Precision measurement of coherent single-pion production cross-sections, with particular attention to target A-dependence. NC coherent pion production is a significant background for next-generation of neutrino oscillation experiments probing $\nu_\mu \rightarrow \nu_e$ oscillation. A sample of **85 K** CC events is expected off carbon. The expected NC sample is roughly half the CC sample.
4. Examination of nuclear effects in neutrino interactions, including final-state modifications in heavy nuclei, by employing carbon, iron and lead targets. These effects play a significant role in neutrino oscillation experiments measuring ν_μ disappearance as a function of E_ν. It has recently been suggested that, for a given Q^2, shadowing can occur at much lower energy transfer (ν) for neutrinos than for charged leptons. This effect is unaccounted for in neutrino event generators. With sufficient $\overline{\nu}$ running, a study of flavor-dependent nuclear effects can also be performed. Due to the different mix of quark flavors, this is another way in which neutrino and charged-lepton nuclear effects differ. MINERνA will collect over **1.5M** CC events off both iron and lead, in addition to the carbon sample.
5. Study of nuclear effects on $\sin^2\theta_W$ measurements, and the NC/CC ratio for different nuclear targets.
6. Exploration of the W (hadronic mass) transition region where resonance production merges with deep-inelastic scattering (DIS), testing phenomenological models like quark/hadron duality. A sample of **2.0 M** multi-pion events is expected withW ≤ 2.0 GeV.
7. With a sample of over **4.1 M** CC DIS events, a much-improved measurement of the parton distribution functions, particularly at large x_{Bj}, will be possible using a measurement of all three ν structure functions. Although we expect over **100 K** CC$\overline{\nu}$ events in the four year MINERνA ν run, an additional dedicated $\overline{\nu}$ run would be required to measure the three $\overline{\nu}$ structure functions with similar precision.
8. Examination of the leading exponential contributions of perturbative QCD.
9. With nearly **230 K** fully reconstructed exclusive events[**?**], precision measurement of exclusive strange-production channels near threshold. This will significantly improve our knowledge of backgrounds in nucleon-decay searches. Also, determination of V_{us}, and searches for strangeness-changing neutral-currents and candidate pentaquark resonances will be undertaken Measurement of hyperon-production cross-sections, including hyperon polarization, is feasible with exposure of MINERνA to $\overline{\nu}$ beams.

10. Improved determination of the effective charm-quark mass (m_c) near threshold, and new measurements of V_{cd}, $s(x)$ and, independently, $\overline{s}(x)$.

These are worthy research topics in their own right, and improved knowledge in most is essential to minimizing systematic uncertainties in neutrino-oscillation experiments. The remainder of this section provides more detail, and illustrates the rich physics potential of MINERνA.